MUON ANOMALOUS MAGNETIC MOMENT AND SUPERSYMMETRIC DARK MATTER

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The anomalous magnetic moment of the muon has recently been measured to be in conflict with the Standard Model prediction with an excess of 2.6σ. Taking this result as a measurement of the supersymmetric contribution, we find that at 95% confidence level it imposes an upper bound of about 500 GeV on the neutralino mass and forbids higgsino dark matter. More interestingly, it predicts an accessible lower bound on the direct detection rate, and it strongly favors models detectable by neutrino telescopes. Cosmic ray antideuterons may also be an interesting probe of such models.

1 Experimental Measurement

Recently, the Brookhaven AGS experiment 821 measured the anomalous magnetic moment of the muon $a_\mu = (g-2)/2$ with three times higher accuracy than it was previously known[1]. Their result is larger than the Standard Model prediction,

$$a_\mu(\mathrm{exp}) - a_\mu(\mathrm{SM}) = (43 \pm 16) \times 10^{-10}. \tag{1}$$

representing an excess of 2.6σ from the standard model value[2]. One well-known possibility is that supersymmetric corrections to a_μ are responsible for this discrepancy[3]. We take the approach that all of the measured discrepancy is due to supersymmetric contributions, and discuss the implications for neutralino dark matter. In this work we require[4]

$$10 \times 10^{-10} \leq \Delta a_\mu(\mathrm{SUSY}) \leq 75 \times 10^{-10}. \tag{2}$$

2 Supersymmetric Models

The lightest stable supersymmetric particle in the Minimal Supersymmetric Standard Model (MSSM) is most often the lightest of the neutralinos, which are superpositions of the superpartners of the neutral gauge and Higgs bosons,

$$\tilde{\chi}^0_1 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}^0_1 + N_{14}\tilde{H}^0_2. \tag{3}$$

We define the gaugino / higgsino ratio of the lightest neutralino as

$$\frac{Z_g}{1-Z_g} = \frac{|N_{11}|^2 + |N_{12}|^2}{|N_{13}|^2 + |N_{14}|^2}. \tag{4}$$

For large regions of the MSSM parameter space, the relic density $\Omega_\chi h^2$ of the lightest neutralino is of the right order of magnitude for the neutralino to constitute the dark matter in the Universe[5]. Here Ω_χ is the density in units of the critical density and h is the present

Table 1. The ranges of parameter values used in the MSSM scans of Refs. [8,9,11,12,13]. We use approximately 79,000 models that were not excluded by accelerator constraints before the recent a_μ measurement.

Parameter	μ	M_2	$\tan\beta$	m_A	m_0	A_b/m_0	A_t/m_0
Unit	GeV	GeV	1	GeV	GeV	1	1
Min	-50 000	-50 000	1.0	0	100	-3	-3
Max	50 000	50 000	60.0	10 000	30 000	3	3

Hubble constant in units of 100 km s^{-1} Mpc^{-1}. Present observations favor $h = 0.7 \pm 0.1$, and a total matter density $\Omega_M = 0.3 \pm 0.1$, of which baryons contribute roughly $\Omega_b h^2 \approx 0.02$[6]. Thus we take the range $0.052 \leq \Omega_\chi h^2 \leq 0.236$ as the cosmologically interesting region, and exclude models that do not satisfy this constraint.

We have explored a variation of the MSSM using the DarkSUSY code[7]. Our framework has seven free parameters: the higgsino mass parameter μ, the gaugino mass parameter M_2, the ratio of the Higgs vacuum expectation values $\tan\beta$, the mass of the CP–odd Higgs boson m_A, the scalar mass parameter m_0 and the trilinear soft SUSY–breaking parameters A_b and A_t for third generation squarks. The only constraint from supergravity that we impose is gaugino mass unification[8,9,10]. We have used a database of MSSM models[8,9,11,12,13] with one–loop corrections for the neutralino and chargino masses[14], and leading log two–loop radiative corrections for the Higgs boson masses[15]. The database contains a table of neutralino–nucleon cross sections and expected detection rates for a variety of neutralino dark matter searches. The database also contains the relic density of neutralinos $\Omega_\chi h^2$, which includes resonant annihilations, threshold effects, finite widths of unstable particles, all two–body tree–level annihilation channels of neutralinos, and coannihilation processes between all neutralinos and charginos[9,16].

We examined each model in the database to see if it is excluded by the most recent accelerator constraints. The most important of these are the LEP bounds[17] on the lightest chargino mass and on the lightest Higgs boson mass m_h, and the constraints from $b \to s\gamma$[18].

3 Dark Matter Detection

The most pronounced effect of applying the Δa_μ(SUSY) bound is an upper limit of about 500 GeV on the neutralino mass. The previous bound of 7 TeV was cosmological[9], that is from the constraint $\Omega_\chi h^2 < 1$. Furthermore, the neutralino must have at least a 10% admixture of gauginos, namely neutralino dark matter can not be very purely higgsino-like, as seen in the top left panel of Fig. 1.

Neutralinos in the galactic halo are constantly passing through the Earth, and may be detectable with sensitive underground instruments such as CDMS[19] and DAMA[20]. The neutralino–nucleon elastic scattering cross section is correlated with Δa_μ(SUSY)[21]. In the top right panel of Fig. 1, we plot the spin-independent neutralino-proton scattering cross section. The constraint due to Δa_μ(SUSY) places a bound that is conceivably detectable in future experiments, such as GENIUS[22].

Another possible method to detect neutralino dark matter is neutrino telescopes, such as at Lake Baikal[23], Super-Kamiokande[24], in the Mediterranean[25], and the south pole[26]. Neutralinos in the galactic halo undergo scatterings into bound orbits around the Earth

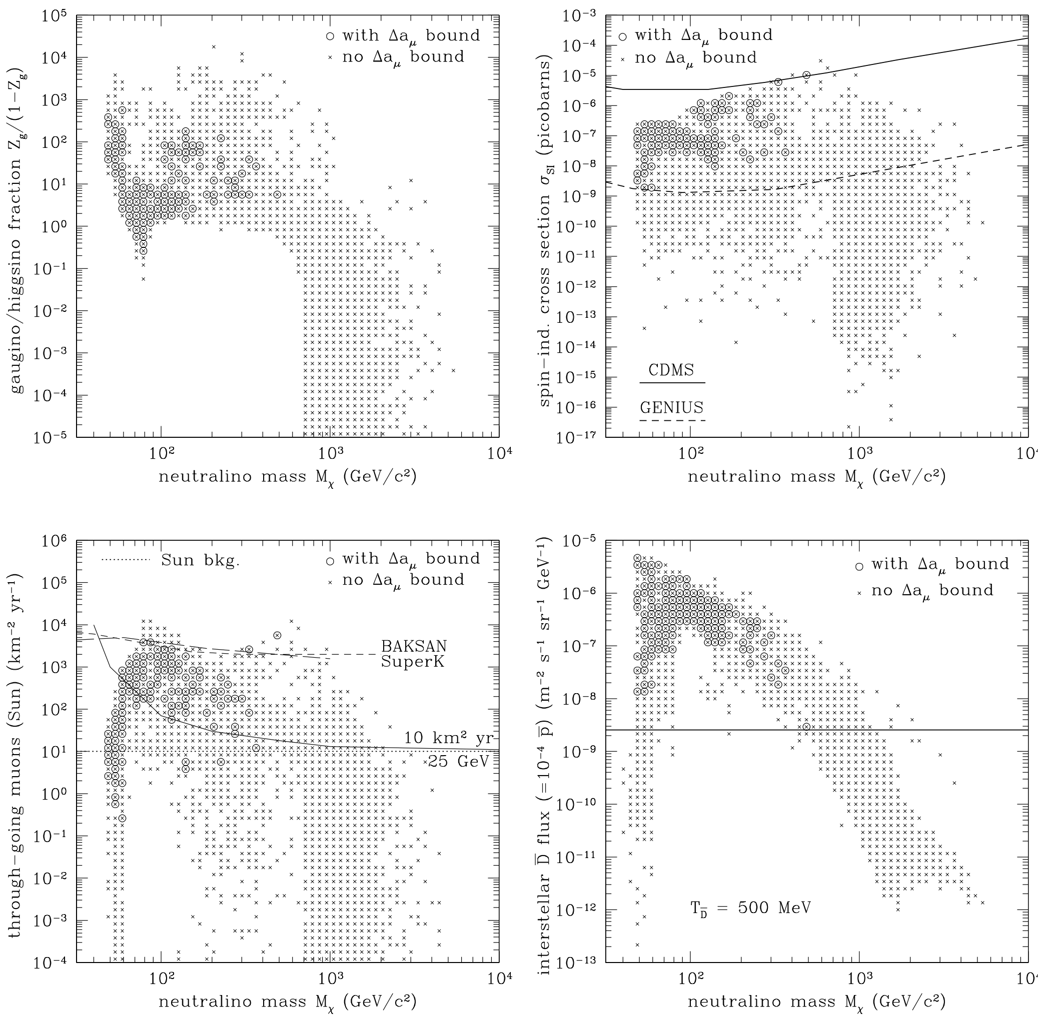

Figure 1. Scan of supersymmetric parameter space, before and after the Δa_μ(SUSY) constraint. Allowed models are plotted with circles. In the top left, we plot the gaugino / higgsino ratio against the neutralino mass. In the top right, we plot the elastic scattering cross section with present and future experimental reach. In the bottom left we plot the muon flux induced by neutrinos from the Sun, again with present and future experimental reach. In the bottom right we plot an estimate of the antideuteron flux, with future experimental reach.

and Sun, and subsequently sink to the centers of these bodies and annihilate, producing a neutrino signal at GeV and higher energies. To illustrate, we plot the rate of neutrino-induced through-going muons from the Sun, along with the unsubtractable background, in the bottom left panel of Fig. 1. We see that the Δa_μ(SUSY) bound removes most undetectable models, except for some with threshold effects[12].

One final interesting possibility is that neutralino annihilation in the galactic halo can produce an observable flux of antideuterons[27]. At low energies, the background should be smaller than for antiprotons, and a signal may be detectable in future experiments[28], as seen in the bottom right of Fig. 1.

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